Hydraulic Modeling of the Floodplain in Sanderson, TX

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CE394K- Surface Water Hydrology

Background

Sanderson is a small town in West Texas about 20 miles north of the Mexican border. The watershed above Sanderson extends approximately 33 miles west of the town and covers a drainage area of about 216 square miles (Scogin, 1995). Sanderson Creek passes through the south side of town, and in times of heavy rainfall, this ephemeral stream can fill up with water and sometimes overflow its banks. The steep, rocky terrain and the topography of the area make the town of Sanderson, TX susceptible to flash flooding, and in 1965 the town experienced a devastating flood that wiped out many houses and infrastructure and killed 26 people (USDA Soil Conservation Service, 1969).

Figure 1- Photo of the destruction from the 1965 flood; Source: (USDA Soil Conservation Service, 1969)

According to Edelmira Calzada, one of the survivors of the 1965 flood, “It was like the last day on earth.” Because of the destruction resulting from the flood of June 11, 1965, a series of eleven flood control dams were built upstream of Sanderson by the Soil Conservation Service (SCS). The $34 million project was designed to capture the 100-year storm and protect the town of Sanderson from damages due to flash flooding. The residents of Sanderson say that they have been protected from flooding since the completion of the dam project in the 1980’s, but the FEMA flood maps have not been updated since 1977 and do not reflect the effect of the flood control structures.

The SCS design report proposing the dams project (USDA Soil Conservation Service, 1969) contains at the back a map shown in Figure 2 that depicts the floodplain as it was during the 1965 flood and as it is predicted to be once the dams have been built. It was expected that the resulting reduced flood flow would be largely contained within the stream channel. Some citizens of Sanderson are paying for flood insurance now even though their property is outside this projected “with dam” floodplain. Terrell County, which administers Sanderson, would like to get a Letter of Map Revision from FEMA to codify the reduction in floodplain area resulting from the dam construction. This term project is one part of the preparatory work for getting that Letter of Map Revision.

Other members of the team of students working on this project have studied extensively the hydrology of the watershed upstream of Sanderson and the hydraulics of the flood control dams. As a result of their work, a hydrograph for the flow in Sanderson Creek at Sanderson has been produced, and this data is used to get an idea of the flow that would occur in Sanderson. The purpose of this report is to study the hydraulics of the flow in Sanderson Creek in the area around the town of Sanderson to determine if any conclusions can be drawn about the new floodplain with the effect of the dams.

Figure 2- Predicted effect of the flood control dams on the 100 year floodplain; Source: (USDA Soil Conservation Service, 1969)

Methodology

The general process that our team is using for the study of the floodplain in Sanderson can be seen in Figure 3. The terrain preprocessing was done by Laura Hurd. The hydraulic model of the dams was done by Cody Hudson, and those results were used as inputs of the hydrologic model of the watershed done by Marcelo Somos in HEC-HMS. The output of the HEC-HMS model is a streamflow hydrograph that can be used as the input for the hydraulic model of the area around Sanderson. The results of the hydraulic model can be imported into ArcGIS to create a map delineating the inundated area. This report focuses primarily on the process of hydraulic modeling of the floodplain in HEC-RAS (US Army Corps of Engineers- Hydrologic Engineering Center, 2010).

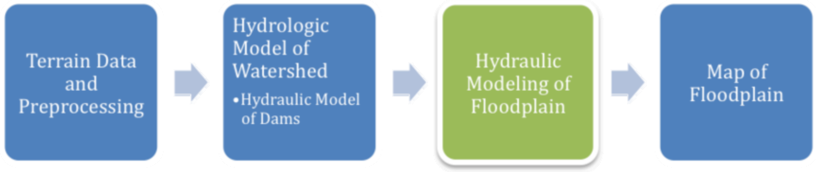


Figure 3- Depiction of the process of the Sanderson flood study

The hydraulic modeling process begins with preprocessing in HEC-GeoRAS (US Army Corps of Engineers- Hodrologic Engineering Center, 2009). HEC-GeoRAS can be installed as a toolbar in ArcGIS, and it allows the user to create shapefiles of the stream centerline, the bank lines, and cross sections that are then connected to a digital elevation model (DEM) to create cross-section profiles and calculate the reach lengths. Figure 4 shows an image of the stream centerlines, bank lines, and cross-section cut lines used in the HEC-GeoRAS preprocessing along with the profile of one of the cross-section cut lines.

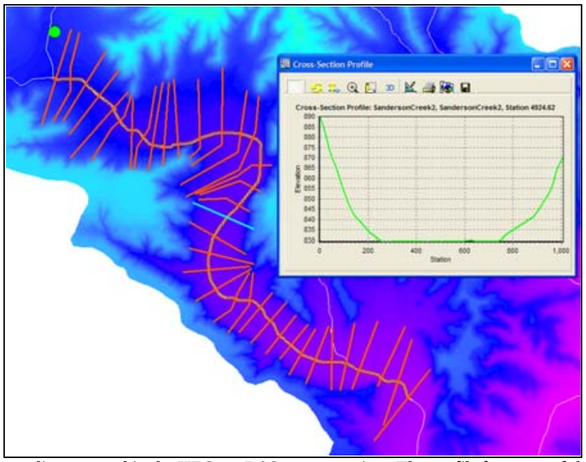


Figure 4- Stream centerline and cross section cutlines created in the HEC-geoRAS preprocessing. The profile from one of the cross section cutlines is shown in the inset.

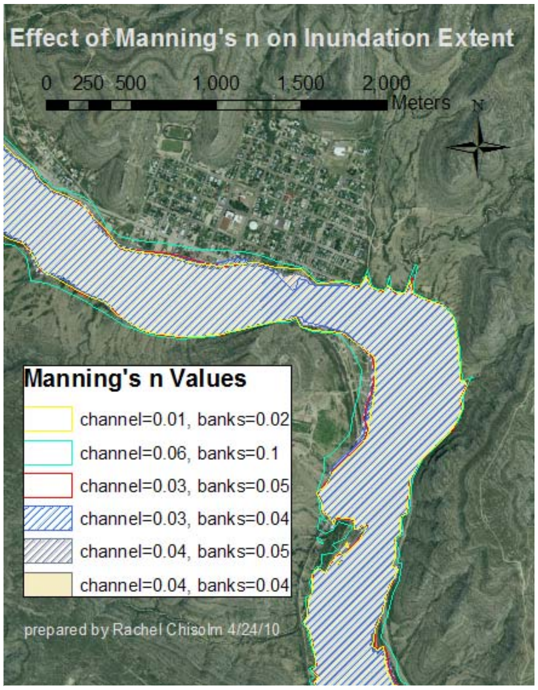
The digital terrain model (DTM) that was used for this study was taken from the National Elevation Dataset (NED) (US Geological Survey), and it is a 10 m (1/3 arcsecond) grid. The output from HEC-GeoRAS can then be imported into HEC-RAS to create a geometry file that is the basis of the hydraulic model. The hydraulic modeling for the town of Sanderson was done with the US Army Corps' River Analysis System (HEC-RAS). After importing the geometric data from HEC-GeoRAS, the values of Manning's n can be added for the channel and the overbanks. The Manning's n values were calibrated based on the steady state model of the 1965 flood. The last thing needed for the subcritical steady state model is the flow rate and the downstream boundary condition. For the steady state models, the flow rates used were the peak flow rates from the hydrographs resulting from the hydrologic model of the upstream watershed. The normal depth, calculated in HEC-RAS based on the channel slope, was used as the downstream boundary condition, and a value of 0.007 was used as the channel slope, roughly equivalent to the slope of the terrain where the channel is located. After the steady model was run and calibrated, an unsteady model was run. The hydrographs at the upstream and downstream ends of the model domain were used as the boundary conditions in the unsteady model. After the model is run in HEC-RAS, the results can be exported in GIS format. The HEC-geoRAS tools can be used to import the data into ArcGIS. The water surface elevations from HEC-RAS are extrapolated to the DTM to delineate the floodplain boundary and to map the depth of inundation. From this, a map of the floodplain can be created, assuming that accurate enough terrain data is available.

Model Setup and Parameters

Using the HEC-GeoRAS tools, cross-sections were cut approximately every 300 m perpendicular to the stream centerline. The stream centerline was drawn based on the flow line delineated from the NED. This flowline closely followed the National Hydrography Dataset (NHD) flowlines (US Gelological Survey) with the exception of one section just downstream of the large bend in Sanderson Creek as it leaves the town. In that section the NHD flowlines more closely follow the ortho imagery of the area, which indicates that the difference is most likely due to the inaccuracy of the DTM. The Manning's n values for the channel and overbanks were estimated based on values given in Chow's book, *Open-Channel Hydraulics* (Chow, 1959). Figure 5 shows a photo of a stream with a Manning's n value of 0.03 that looks relatively similar to the channel of Sanderson Creek, so a value of n=0.03 for the channel and a slightly higher value of n=0.05 for the floodplain were used as starting values.

Figure 5- Example of a channel with a Manning's n value of 0.03; Source: (Chow, 1959)

The Manning's n values were calibrated based on a model of the 1965 flood, which had an estimated peak flow of approximately 100,000 cfs (Crawley, 1969). In Figure 6 it can be seen that small changes in the value of Manning's n do not significantly affect the model results. If the Manning's n values are increased significantly, the inundated area increases, but these higher Manning's n values are not realistic. The actual extent of the 1965 flood, seen in Figure 7, more closely resembles the results produced by lower Manning's n values. Ultimately, the original values of n=0.03 for the channel and n=0.05 for the overbanks were used.



Disclaimer: Map is based on a 10 m digital terrain model that is too coarse to define an accurate floodplain

Figure 6- Effect of Manning's n values on the steady state model of the 1965 flood (100,000 cfs)

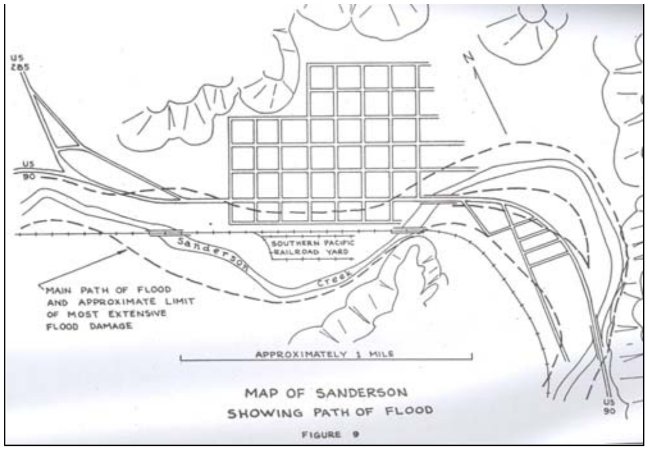


Figure 7- Extent of the 1965 flood; Source: (Crawley, 1969)

The flow rates used for the steady state models were the peak flows from the hydrographs produced by Marcelo Somos' HEC-HMS model, and they are given in Table 1. At the steady state, a subcritical model was run, and the downstream boundary condition was the normal depth calculated from the channel slope, s=0.007. The unsteady model used the hydrographs at Sanderson (just after the junction of the two streams downstream of dam site 11) and the lagoons as the upstream and downstream boundary conditions respectively. The hydrographs at the upstream location are shown in Figure 8.

Table 1- Peak flows for floods of different return period

Return Period of Flood (all flows account for the effect of upstream dams unless otherwise noted)	Peak Flow (cfs)
2 years	2,904
10 years	8,717
25 years	11,363
50 years	13,220
100 years	16,043
500 years	26,731
100 years (without effect of the dams)	43,214

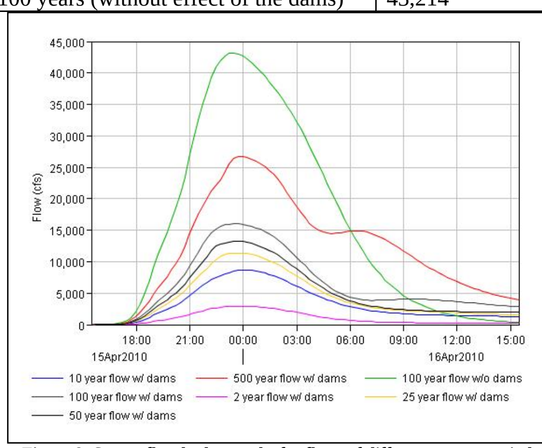
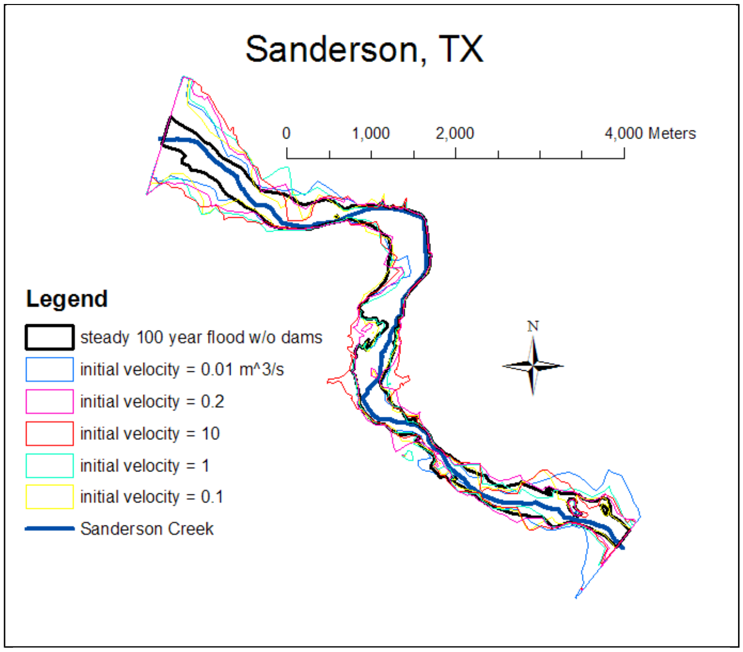


Figure 8- Streamflow hydrographs for flows of different return period

Unsteady Model

As mentioned previously, the stream flow hydrographs are used as the boundary conditions for the unsteady model. Because Sanderson Creek is an ephemeral stream and is normally dry except when rain events occur, the value used for the initial flow was originally zero. The HEC-RAS model did not work with an initial flow of zero, so a very small initial flow was given (values ranging from 0.01 to 10 cfs). These small initial flows may have still been the cause of instabilities in the model, but anything higher than 10 cfs is not very realistic given the characteristics of the stream. The results of the unsteady model of the 100 year storm without dams for various initial flows are compared to the steady state results in Figure 9.



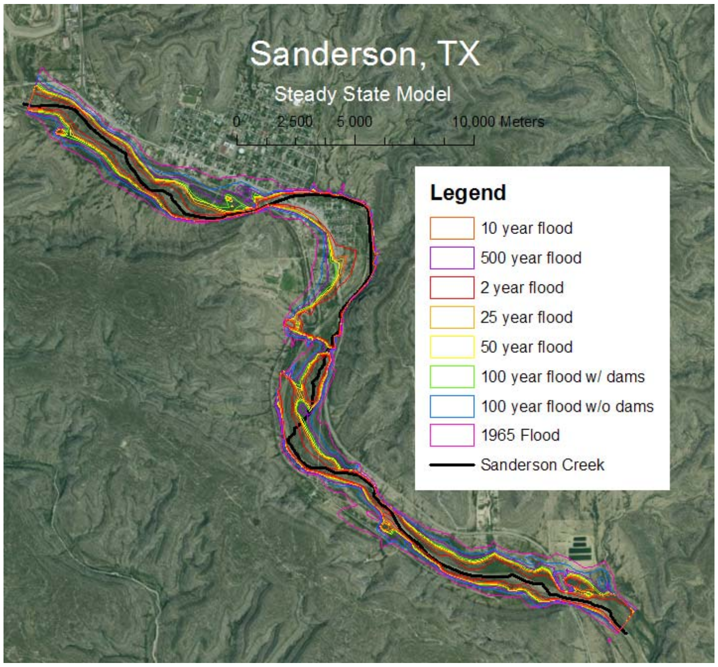
Disclaimer: Map is based on a 10 m digital terrain model that is too coarse to define an accurate floodplain

Figure 9- The effect of initial flow on the unsteady model

It can be seen that increasing the initial flow gives slightly more stable results, but none of the unsteady models gives results good enough to say anything conclusive about the floodplain. In addition, the upstream boundary condition continues to have an unnatural effect on the results in the vicinity of the upstream boundary even for models with higher initial flows. What can be concluded is that the unsteady results are not much different from the steady state results. Since we do not have accurate terrain data, the results from the steady model should be sufficient for our purposes.

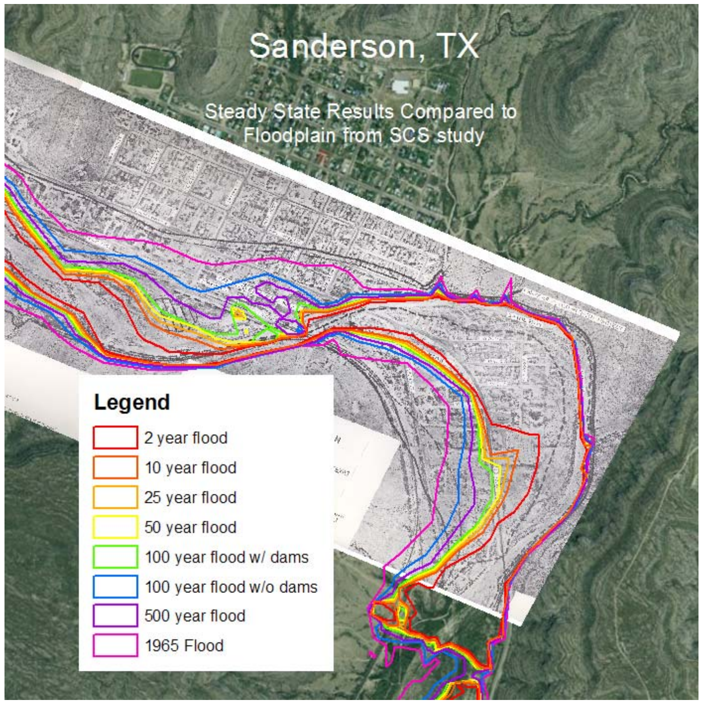
Steady State Results and Discussion

The flow rates used for the steady state models are given in Table 1, and the extent of inundation based on the results of those models is shown in Figure 10. The map produced from the SCS work plan for the flood control structures (Figure 2) has been geo-referenced to the map in Figure 10, and the details can be seen in Figure 11.



Disclaimer: Map is based on a 10 m digital terrain model that is too coarse to define an accurate floodplain

Figure 10- Results of the steady state model



Disclaimer: Map is based on a 10 m digital terrain model that is too coarse to define an accurate floodplain

Figure 11- Results of the steady state model in Sanderson overlaid onto the map from the SCS work plan (Figure 2)

From the map in Figure 11 it is clear that the results are not accurately depicting what is going on. It appears that even the two year flood is overflowing the channel banks, but we know from talking to residents of Sanderson that this is not the case because Sanderson Creek has not left its banks in the town of Sanderson since the flood control dams were constructed. A drastic decrease in flow does not appear to have much effect on the floodplain. The reason why the change in flow rate does not seem to have more effect on the model results can be seen by looking at the NED in Figure 12. In the area where the town of Sanderson lies, there does not appear to be much variation in elevation, and by looking at the terrain data alone, it is difficult to tell where the channel of Sanderson Creek lies. During our visit to Sanderson, we found that Sanderson Creek does have a very well defined channel, particularly in the large bend in the creek as it leaves Sanderson, but this is not apparent when looking at the DTM used in this study. When the terrain is depicted on a 10 m grid, much of the variation is smoothed out, so a much finer grid would be needed to get any reliable results. LIDAR has become the industry standard for floodplain mapping, and that is most likely the terrain data that the town of Sanderson needs to get an accurate floodplain map.

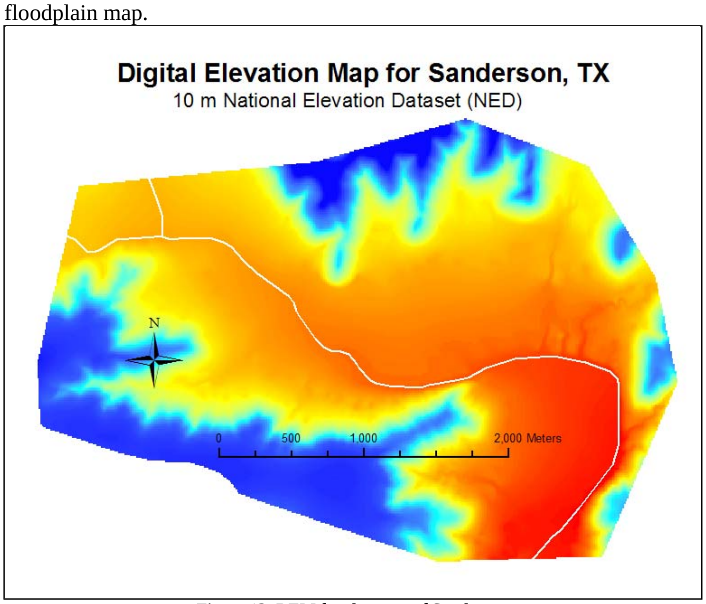


Figure 12- DEM for the town of Sanderson

While the inundation extents shown in Figure 11 are not particularly informative, the depth of inundation, mapped in ArcGIS through the HEC-GeoRAS toolbar, can tell us something about the flow. The depth of inundation for the 100 year flood without the effect of the dams, the 100 year flood with the dams, and the two year flood with the effect of the dams are shown in Figures 13, 14, and 15 respectively. The maximum depth of inundation for the 100 year flow without dams is around 5 m, and this decreases to approximately 3.5 m with the effect of the dams. The 2 year flood has a maximum depth of inundation of approximately 2 m, and it is very probable that this 2 year flood would be contained within the channel.

Disclaimer: Map is based on a 10 m digital terrain model that is too coarse to define an accurate floodplain

Figure 13- Depth of inundation for the 100 year flood without the effect of dams

Disclaimer: Map is based on a 10 m digital terrain model that is too coarse to define an accurate floodplain

Figure 14- Depth of inundation for the 100 year flood with the effect of dams

Disclaimer: Map is based on a 10 m digital terrain model that is too coarse to define an accurate floodplain

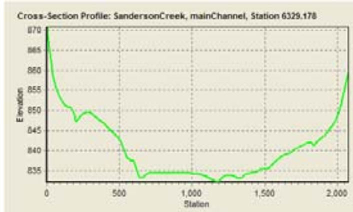
Figure 15- Depth of inundation for the 2 year flood with the effect of dams

While the lack of sufficiently well defined topographic data is the primary problem contributing to the inaccuracy of the hydraulic model in the town of Sanderson, there are a few other contributing factors that were not taken into account in the current model. First, the model was not calibrated with actual measured data. The flow rate and extent of the 1965 flood were estimated based on the damage and high water marks recorded after the flood. For completely accurate calibration, a recorded stage based on a known flow rate should be used. In addition, there are a few structures in the town of Sanderson that could affect the flow that were not taken into account in this study. The railroad tracks could have a similar effect as that of a levee, and there are a couple of bridges in town that would have a backwater effect that should be taken into account. Even though this hydraulic model is incomplete, the main shortfall of the model is the terrain data.

Conclusions

Without more accurate terrain data, we cannot conclude much about the floodplain in Sanderson. It is apparent when looking at the NED in

Sanderson, that a clearly defined channel cannot be seen, and this is needed to determine if the flow for a flood of any return period will be confined to the channel. In addition, the streamlines delineated from the NED do not match up with the imagery and the NHD flowlines in some places, which indicates that the NED is not truly representing the topography. IFSAR (Interferometric Synthetic Aperture Radar) data has been collected for the area around Sanderson, and that terrain data is on a 5 m grid. The profiles for three cross sections taken from the IFSAR data are shown in Figure 16, 17, and 18, and they are compared to the same cross sections taken from the NED DEM. Although the IFSAR cross section in Figure 17 does seem to have a slightly more well-defined channel, there does not appear to be much difference between the IFSAR data and the NED for the other two cross sections. The cross sections in Figures 16 and 18 are both located in the bend in Sanderson Creek (the part of town that was most affected by the 1965 flood) where it is most important to have terrain data that accurately represents the channel definition.



16a- Cross section from NED terrain data

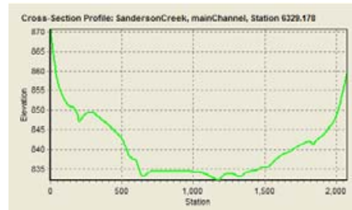


Figure 16b- Cross section from IFSAR terrain data

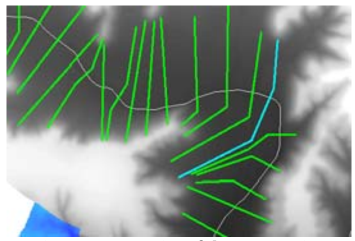


Figure 16c- Location of the cross section

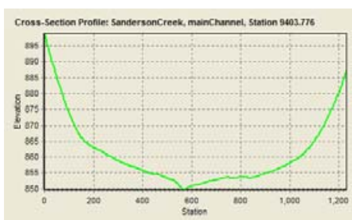


Figure 17a- NED cross section

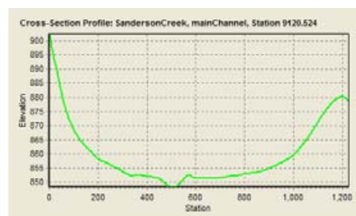


Figure 17b- IFSAR cross section

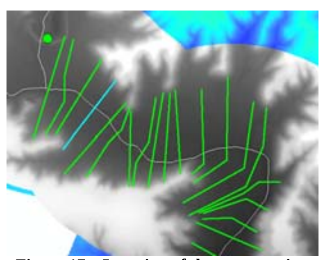


Figure 17c- Location of the cross section

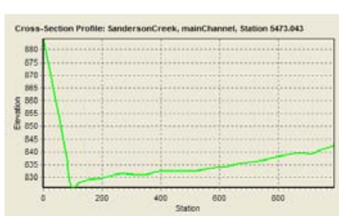


Figure 18a- NED cross section

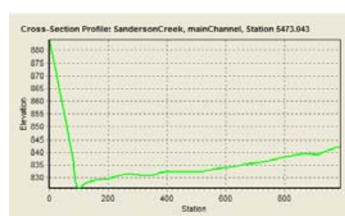


Figure 18b- IFSAR cross section

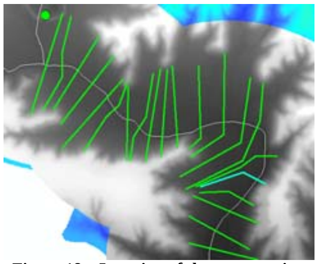


Figure 18c- Location of the cross section

Overall the results of the hydraulic model are inconclusive, and the primary conclusion that everything seems to be leading to is that we need LIDAR data to determine anything about the floodplain in Sanderson.

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